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PHYSICAL MODEL STUDY OF A BARGE MOORING SYSTEM(U) NAVFAC  
FACILITIES ENGINEERING COMMAND WASHINGTON DC CHESAPEAKE  
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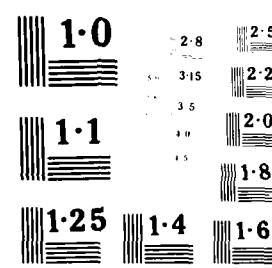
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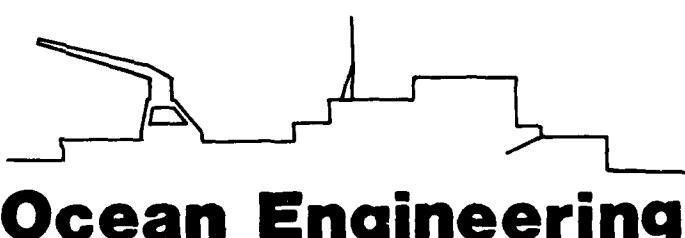
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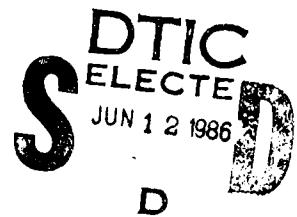
## Ocean Engineering

CHESAPEAKE DIVISION  
NAVAL FACILITIES ENGINEERING COMMAND  
WASHINGTON NAVY YARD  
WASHINGTON, DC 20374

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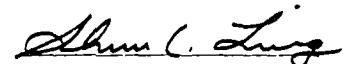
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PHYSICAL MODEL STUDY OF A  
BARGE MOORING SYSTEM  
by  
ARCTEC, Inc.

William N. Seelig  
CHESNAVFACENGCOM EIC  
FPO-1-84(8)  
April 1984

APPROVED BY:



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CHESAPEAKE DIVISION  
NAVAL FACILITIES ENGINEERING COMMAND  
WASHINGTON, D.C. 20374

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ships. Moorings for the EMPRESS II barge and test vessel are being designed  
for the Chesapeake Bay. One of these moorings is to be a site where the barge  
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Test results show that peak dynamic loads are produced when the driving waves force the barge/mooring system into the first mode of oscillation. In this mode of oscillation the barge behaves as a mass and the mooring behaves as a spring. Wave groups seem to drive this long period oscillation, which has periods ranging from one to several minutes.

The attached figure includes the peak mooring load data and a design curve developed by forming an upper envelope over the test results. Hindcast wind speeds required to develop various wave heights are shown on the upper portion of the figure.

## EXECUTIVE SUMMARY

The EMPRESS II is planned to be a 105' x 120' barge that will be used to test ships. Moorings for the EMPRESS II barge and test vessel are being designed for the Chesapeake Bay. One of these moorings is to be a site where the barge can tie up during moderate to small storms.

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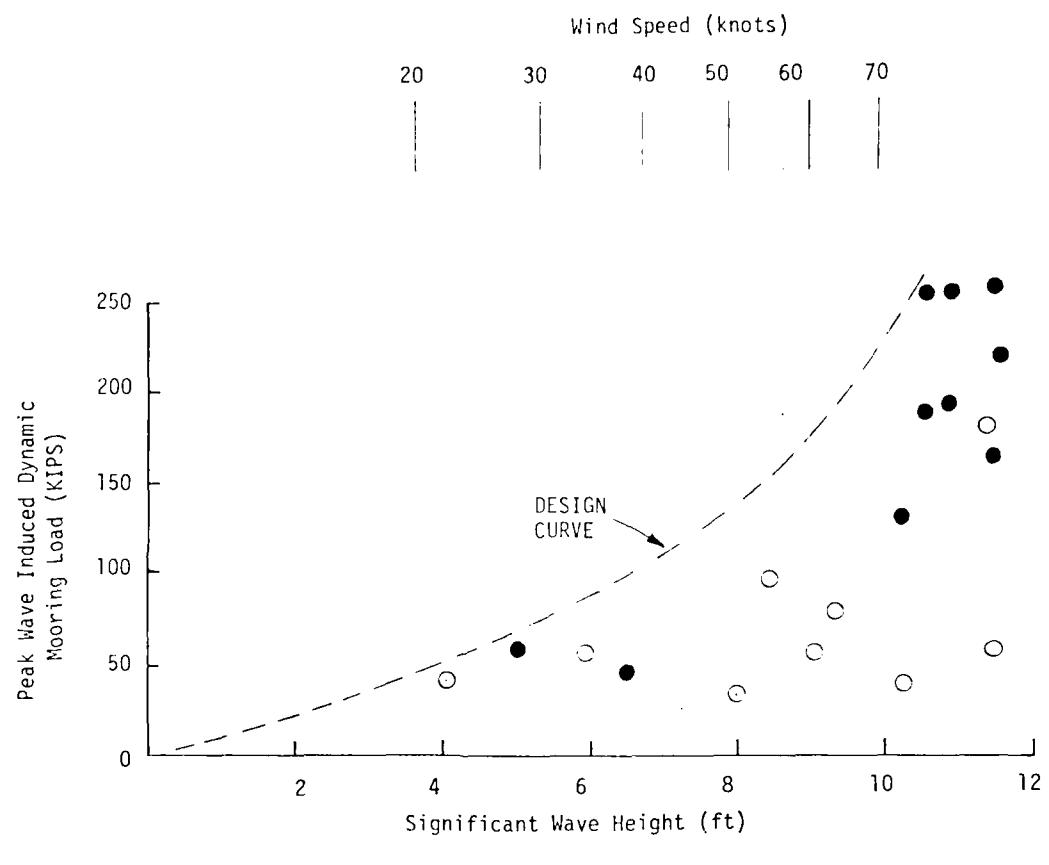
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<b>CHESAPEAKE</b>	<b>DIVISION</b>	PROJECT: <u>EMPRESS II MOORING</u>
Naval Facilities Engineering Command	NDW	Station: <u>CHES BAY - BLOODSWORTH IS</u>
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Calcs made by: <u>W. SEELIG</u>	date: <u>4/4/84</u>	Calculations for: <u>PEAK DYNAMIC MOORING LOAD</u>
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ARCTEC, Incorporated

Report No. 1019C

PHYSICAL MODEL STUDY OF A  
BARGE MOORING SYSTEM

March 1984

by

William G. Grosskopf

Submitted to

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## 1. INTRODUCTION

This report summarizes the physical modeling of a barge and mooring system in shallow water wave conditions to evaluate wave forces that will occur on the structure. A barge and mooring system, conceptually designed by the Chesapeake Division of the Naval Facilities Engineering Command, was modeled at a scale of 1:28 and tested in a wave tank at ARCTEC, Incorporated in Columbia, Maryland. The model was subjected to a variety of regular and random wave conditions with mooring line tension data collected via an HP 2240A Measurement and Control Processor and an HP 9816 microcomputer system. The data was then analyzed by the HP 9816 computer to provide zero up-crossing statistics, cumulative distribution functions and spectral analyses. Video recording of each test were also acquired to document the motions of the barge under the various incident wave conditions.

## 2. TESTING CONDITIONS

The conceptual design of the barge and mooring system is shown as provided by NAVFAC in Figure 2.1. The barge is moored to a large buoy by a chain bridle. The buoy is moored to a heavy sinker which sits on the sea bottom and is in turn moored to an anchor that also resides on the seafloor. The design water depth is 45 feet.

Also provided by NAVFAC was a load-deflection curve for the prototype mooring system which is also presented in Figure 2.1. The curve was developed for the horizontal static loads expected on the system due to wind and current. It is assumed in this study that measured wave forces will linearly superimpose on these static forces.

A wave hindcast was performed by NAVFAC to develop expected wave conditions at the planned prototype site of the structure. This hindcast yielded four wave conditions to be examined in this test program:

TEST CONDITION DESIGNATION	RETURN INTERVAL (YRS)	WIND SPEED (KNOTS)	STATIC FORCE (KIPS)	SIGNIFICANT WAVE HEIGHT (FT)	PEAK WAVE PERIOD (SEC)
A	-	30	26.5	5.3	5.0
B	1	60	69.0	9.0	6.4
C	10	76	102.0	10.3	6.9
D	25	90	139.0	11.5	7.3

## CHESAPEAKE

Naval Facilities Engineering Command NDW

## DIVISION

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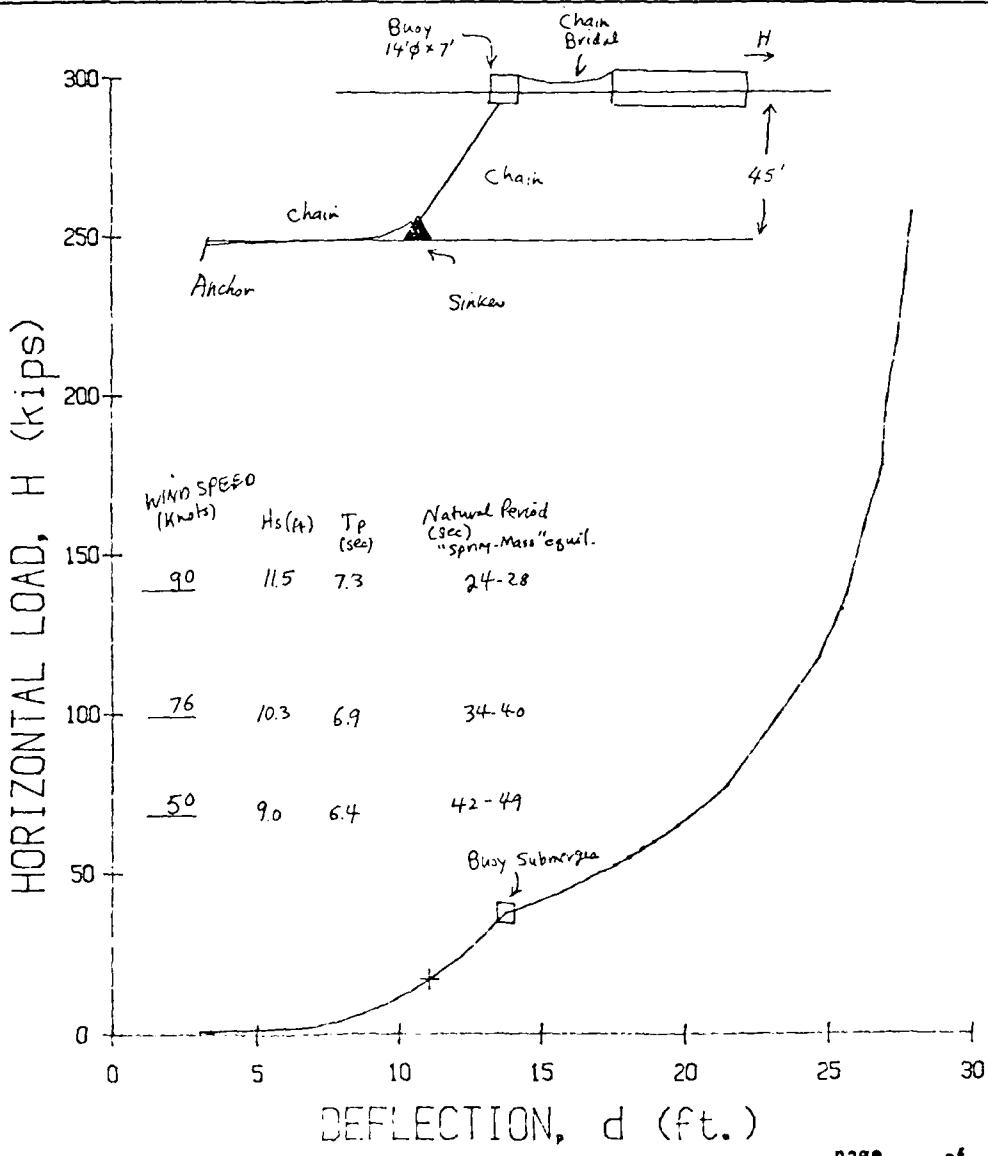
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### 3. MODEL CRITERIA

Based on the above-mentioned test conditions, a two-dimensional model study of the system in waves was requested by NAVFAC. A Froude model at a scale of 1:28 was specified, with model testing in both regular and random waves. The barge model to be used for the test was provided by NAVFAC. This model in prototype measures 105 feet wide by 120 feet long and scaled to 114 cm wide by 131 cm long for testing.

The wave conditions given above were tested in both monochromatic and irregular modes, with the irregular seas specified using the required wave heights as significant wave heights and the wave periods as the peak periods of the wave spectrum. The form of the wave spectrum used was that found typical of shallow water random seas, and is described in the next section. The four wave height-period combinations, given in Section 2, and two sea types (random and regular) were included in a range of 23 tests to study the wave forces experienced by the barge-mooring system.

The mooring, a single point configuration for this test program, was modeled using a series of springs to simulate the nonlinearity of the load-deflection curve. The spring constants were specified to provide the proper total deflection of the system at any given total load. After the desired springs arrived at the laboratory, the springs were "broken in" by applying a cyclical load to the spring. Following the "breaking in" period, the spring constants were re-measured in order to redefine the required extension limits for each spring. The spring constants were as follows for the four-spring system.

<u>Spring</u>	<u>Specified Spring Constant (lb/cm)</u>	<u>Spring Constant After Break-In (lb/cm)</u>
1	0.11	0.115
2	0.39	0.385
3	0.79	0.764
4	2.28	2.284

The range of load for each best-fit line segment of the load deflection curve was chosen as:

<u>Line Segment</u>	<u>Full Scale Load (kips)</u>		<u>Model Scale Load (lbs)</u>	
	<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>
1	0	22	0	1.00
2	22	72	1.00	3.28
3	72	150	3.28	6.83
4	150	270	6.83	12.30

Using these load ranges for each line segment, the deflection of these spring systems for each line segment and the total deflection of each spring is specified:

<u>Spring</u>	<u>EXTENSION (cm)</u>				<u>Total Spring Extension</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	
1	8.47	-	-	-	8.47
2	2.54	5.77	-	-	8.31
3	1.27	2.88	4.50	-	8.65
4	0.44	0.99	1.55	2.41	5.39

System Deflection:

Model Scale (cm)	12.72	9.64	6.05	2.41
Full Scale (ft)	11.68	8.86	5.56	2.21

The mooring system was varied in configuration for each wave condition examined, in order to bring the mooring system to the correct point on the static load-deflection curve before the waves were run. This precaution was chosen to eliminate the need to actually apply a static force to the model during testing. Figure 3.1 shows the load-deflection curve simulated by the four-spring system, and the static loads expected to be concurrently felt by the structure during the four wave conditions. Test Condition 1, the 30-knot wind speed case, falls very low on Segment 2; Test Condition 2, the 60-knot wind speed case, falls very low on Segment 3; Test Condition 3, the 76-knot case, falls midway along Segment 3; and Test Condition 4, the 90-knot case falls very close to the low point of Segment 4. Therefore, a matrix results with the springs and spring extensions as shown in Table 3.1 for each test.

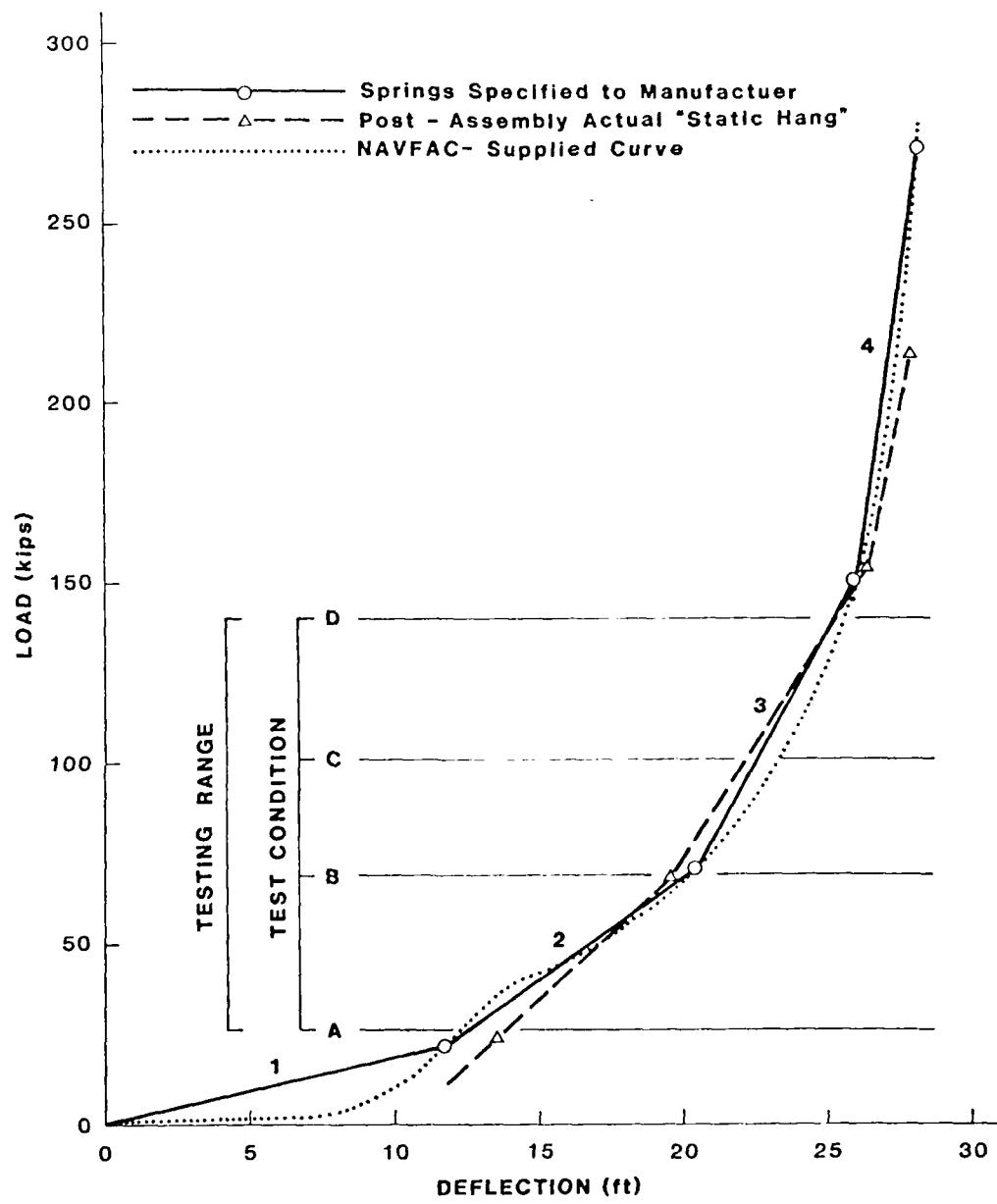


FIGURE 3.1  
LOAD-DEFLECTION OF MODELED MOORING IN PROTOTYPE UNITS

TABLE 3.1  
TEST MATRIX FOR NAVFAC BARGE/MOORING STUDY

Test Number	Wave Condition*	Prototype		Model Scale		Mooring Spring Extensions (cm)			
		Height (ft)	Period (sec)	Height (cm)	Period (sec)	1	2	3	4
1	Regular	5.3	5.0	5.8	0.95	Leave out of System	8.31	8.66	No Limit
	Random	5.3	5.0	5.8	0.95	Leave out of System	8.31	8.66	
3	Regular	9.0	6.4	9.8	1.21	Leave out of System	2.21	2.21	
	Random	9.0	6.4	9.8	1.21	Leave out of System	2.21	2.21	
4	Regular	10.3	6.9	11.2	1.30	Leave out of System			
	Random	10.3	6.9	11.2	1.30	Leave out of System			
6	Regular	11.5	7.3	12.5	1.37	Leave out of System			
	Random	11.5	7.3	12.5	1.37	Leave out of System			
7	Regular								
	Random								

\* Random wave conditions were generated with the significant height and peak wave period corresponding to that reported here.

#### 4. TEST BASIN CONFIGURATION

The tests were performed in ARCTEC's Coastal Wave Tank facility, which is 100 feet long, 12 feet wide and up to 10 feet deep. The waves are generated by a hydraulically-driven piston-type wavemaker. The wavemaker signals were calculated by an APPLE II Plus computer system which superimposes up to 50 sinusoidal wave components and updates the wavemaker position every 0.01 seconds. Bales of stainless steel turnings were placed along the far end of the tank to effectively dissipate wave energy with a minimum of reflection.

Two wave probes and one tension link were used to collect data in the tests. The wave probes were capacitance type and positioned two feet apart in front of the barge model to facilitate wave reflection analysis and to provide duplication of wave measurement. The tension link was a strain gage-type of sensor installed in the mooring line. All data was collected at a rate of 16 Hz by the HP 9816S computer system. Video was also taken of each test. Figure 4.1 illustrates the basin configuration for the tests.

Random wave conditions were generated by first numerically deriving a shallow water wave spectrum parameterized in shape according to recent studies of shallow water spectral forms (Vincent, 1981). Each spectrum was sliced into frequency segments all of equal area which were converted to monochromatic wave components. The components had a period corresponding to the central frequency of the area slice and a height which provided the proper amount of energy to the water surface. These components were recorded on floppy disk. During a test run, the computer randomly assigned each component a phase angle and then superimposed all the components on a real time basis every 0.01 seconds.

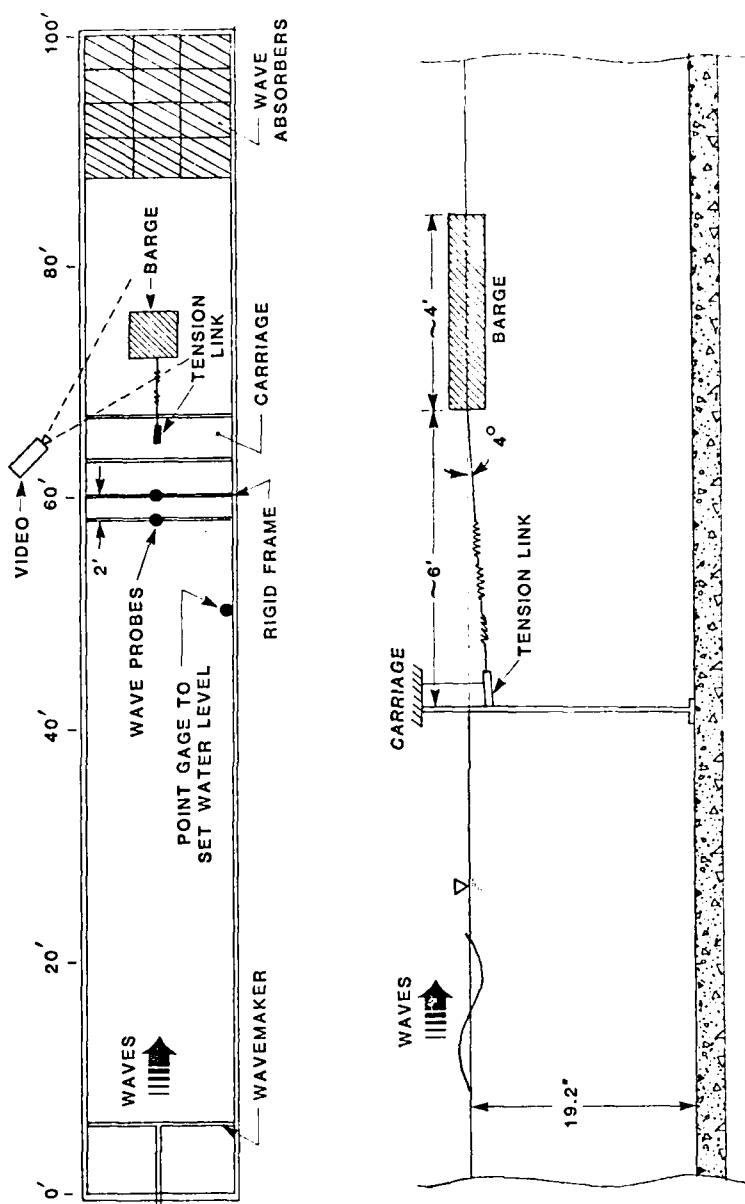


FIGURE 4.1 SCHEMATIC OF WAVE BASIN AND TESTING CONFIGURATION

## 5. DATA ANALYSIS PROCEDURES

The data collected included:

- Mooring Tension Measurements
- Wave Measurements
- Video Tape Recordings

The tension and wave records were written digitally to HP 9816S microdisks along with zeroes and calibration constants for each test. The following analyses were performed on the data:

- Time Series Plot
- Zero-Upcrossing
- Fast-Fourier Transform
- Cumulative Distribution Function

All the results of the analyses are shown in Section 6.

### Zero-Upcrossing Analysis

A zero-upcrossing analysis was performed on the digital data to provide:

- Mean Crest-To-Trough Height
- RMS Height
- Significant Height (Average of Highest One-Third)
- Largest Crest-To-Trough Height
- Period Of The Significant Height
- Mean Period
- Number of Waves
- Crest Height/Crest-To-Trough Height
- Height Of Wave Crest/Period Of Entire Wave

Initially, the mean of the time series was calculated and subtracted from every data point. The RMS Height was then found by:

$$\text{RMS Height} = 4 \left( \sum_{I=1}^N H^2(I) \right)^{1/2}$$

The Significant Height,  $H_{sig}$ , was determined by averaging the highest one-third zero-upcrossing wave heights and the period of the significant height,  $T_{sig}$ , was found by averaging the period associated with those waves included in the calculation of  $H_{sig}$ .

#### Fast Fourier Transform

The time series was then passed through an FFT routine to indicate peak response frequencies of the mooring tension and wave channels. The resulting energy spectra are plotted in energy-density or "force-density" units. Normally a total of 4096 data points were processed at 16 Hz and plotted after band-averaging eight spectral lines. The resulting band width was 0.03125 Hz. Phase spectra were also presented on a line-by-line basis.

#### Cumulative Distribution Function

The trough-to-crest wave heights (or zero-to-peak force heights) were ranked and plotted on a normal probability plot. This data should give some indication of the form of the distribution of wave-induced mooring forces.

## 6. TIME SERIES AND ANALYSES

Twenty-three tests were run to provide NAVFAC with more of a range of wave conditions and force data to analyze the forces on the barge. This range of wave conditions encompassed the targeted wave conditions originally outlined by NAVFAC and shown in Table 3.1. The actual tests that were performed are listed below. The detailed data and analysis results follow.

TEST	MAXIMUM FORCE (N)	WAVE CONDITION		TEST LENGTH	WAVE TYPE
		HT (CM)	PER (S)**		
1	11.3	10.0	0.93	60 sec	Regular
2	8.0	4.5	0.87	60 sec	Regular
3	18.5	9.3	0.92	60 sec	Regular
4	11.8	12.5	0.91	60 sec	Regular
5	8.4	7.2	0.85	120 sec	Random
6	11.2	5.5	0.85	120 sec	Random
7	7.5	11.2	1.17	60 sec	Regular
8	3.4	6.5	1.17	60 sec	Regular
9	5.8	8.9	1.17	60 sec	Regular
10	25.1	11.3	1.06	120 sec	Random
11	21.7	14.6	1.26	60 sec	Regular
12	11.2	17.9	1.25	60 sec	Regular
13	31.1	19.1	1.26	60 sec	Regular
14	39.0	11.7	1.18	120 sec	Random
14a	39.0	11.6	1.24	300 sec	Random
15	50.8	11.6	1.27	120 sec	Random
15a	50.8	11.8	1.27	300 sec	Random
16	36.0	12.1	1.33	120 sec	Regular
17	15.1	10.1	1.33	120 sec	Regular
18	42.8	14.2	1.33	120 sec	Regular
19	37.5	12.4	1.31	120 sec	Random
19a	52.1	12.7	1.30	300 sec	Random
20	32.5	12.5	1.31	120 sec	Random
20a	44.0	12.7	1.31	300 sec	Random
21	32.4	16.6	1.45	120 sec	Regular
22	34.0	19.0	1.45	120 sec	Regular
23	31.0	14.8	1.69	120 sec	Regular

\* If an unusually large first wave occurred in a test, it was disregarded.

\*\* Random wave peak periods appear slightly low because band averaging over 0.05 Hz was used in analysis. Consequently, the period of highest significant energy in the band of peak energy is  $INV [0.05 + 1/T_s]$ .

6. TIME SERIES AND ANALYSIS PLOTS

PROJECT NO. 10190 DATE: MARCH 16, 1984  
TIME: 13:43:43

CH. POINT EMA, VMA, 12 MILLIVOLTS

1	+0.0000E+00	0
2	+1.0000E+00	200
3	+2.0000E+00	405
4	+3.0000E+00	600
5	+4.0000E+00	7412
6	+5.0000E+00	2017
7	+6.0000E+00	2432
8	+7.0000E+00	3032
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10	+9.0000E+00	5046
11	+1.0000E+01	5045
12	+4.0000E+00	8062

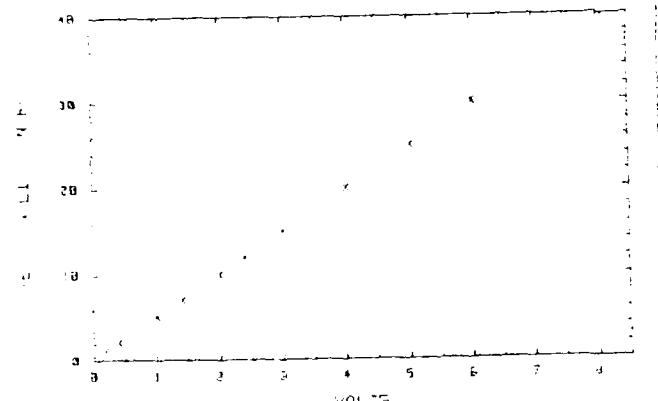
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TRD = 1.13427897859 MILLIVOLTS

RELATION COEF. = .999999730098

SAIN = 4400

OCITATION = 10



CALIBRATION FOR CHANNEL 1: TENSION LINE

PROJECT NO. 10190 MARCH 16, 1984 13:43:43

#### CALIBRATION SUMMARY

DATA FROM CHANNEL 2: WAVE PROBE 11

DATA FROM CHANNEL 2: WAVE PROBE 11  
TIME: 14:25:54

CH1, P0017

CH2, M4C17

MIL. INCHES

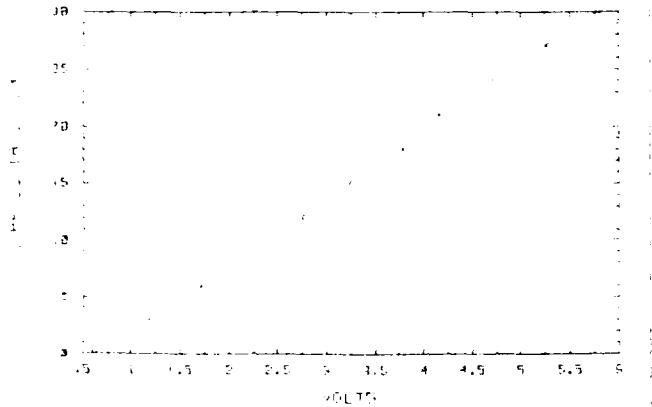
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2	+2.00000E-01	1165
3	+6.00000E-01	1712
4	+9.00000E+00	2229
5	+1.20000E+01	2747
6	+1.50000E+01	3255
7	+1.80000E+01	3762
8	+2.10000E+01	4269
9	+2.40000E+01	4776
10	+2.70000E+01	5283
11	+3.00000E+01	5790

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XIN = 2

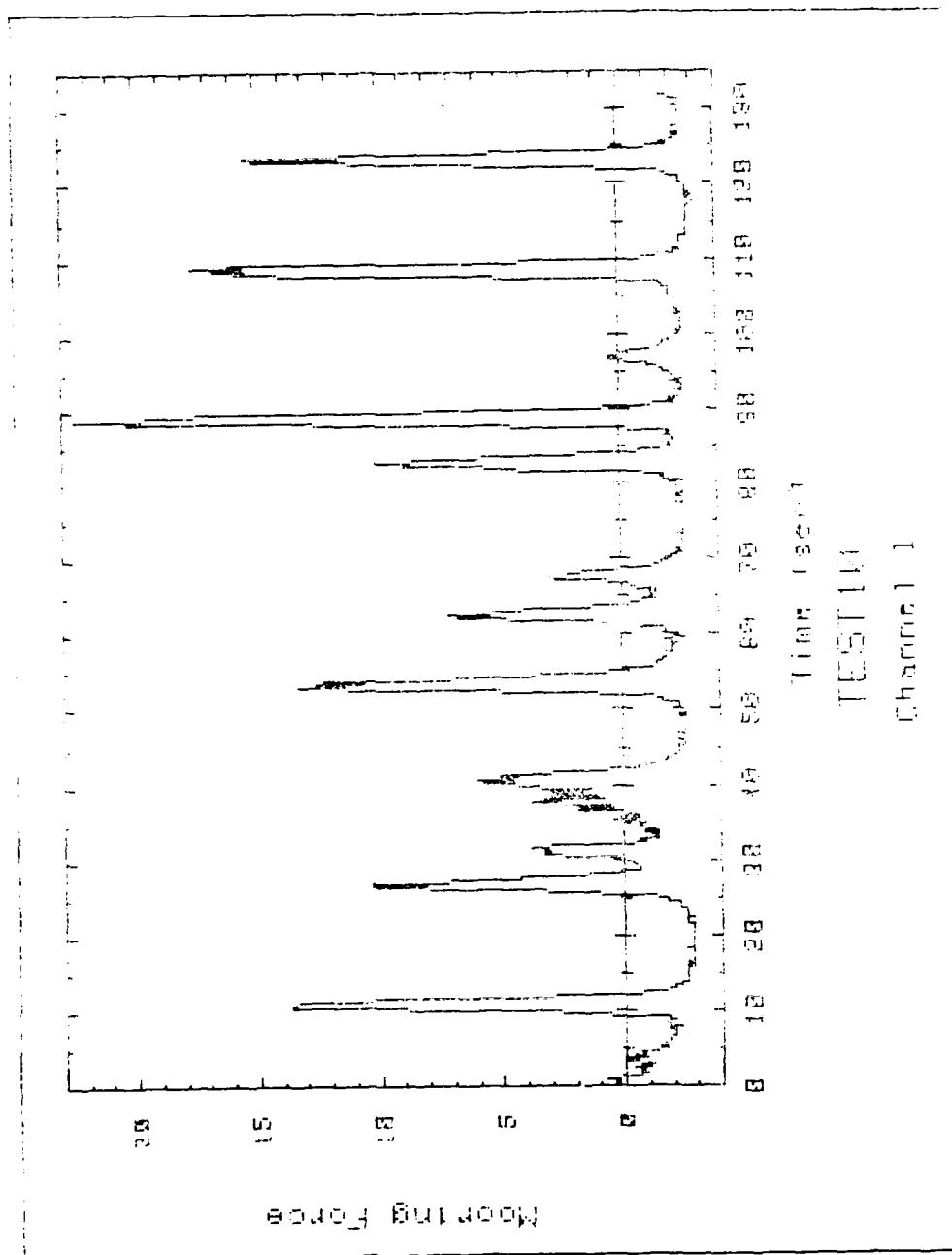
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RECORDED BY: JMMAR

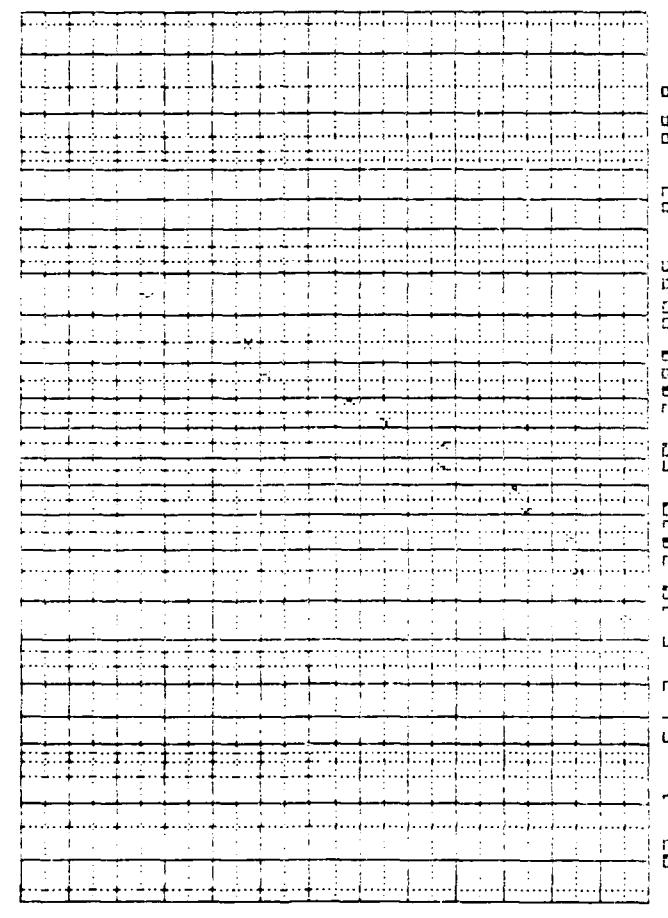
APPENDIX - COMPUTER OUTPUT FOR A  
SAMPLE RUN (TEST 10)



Time (min)

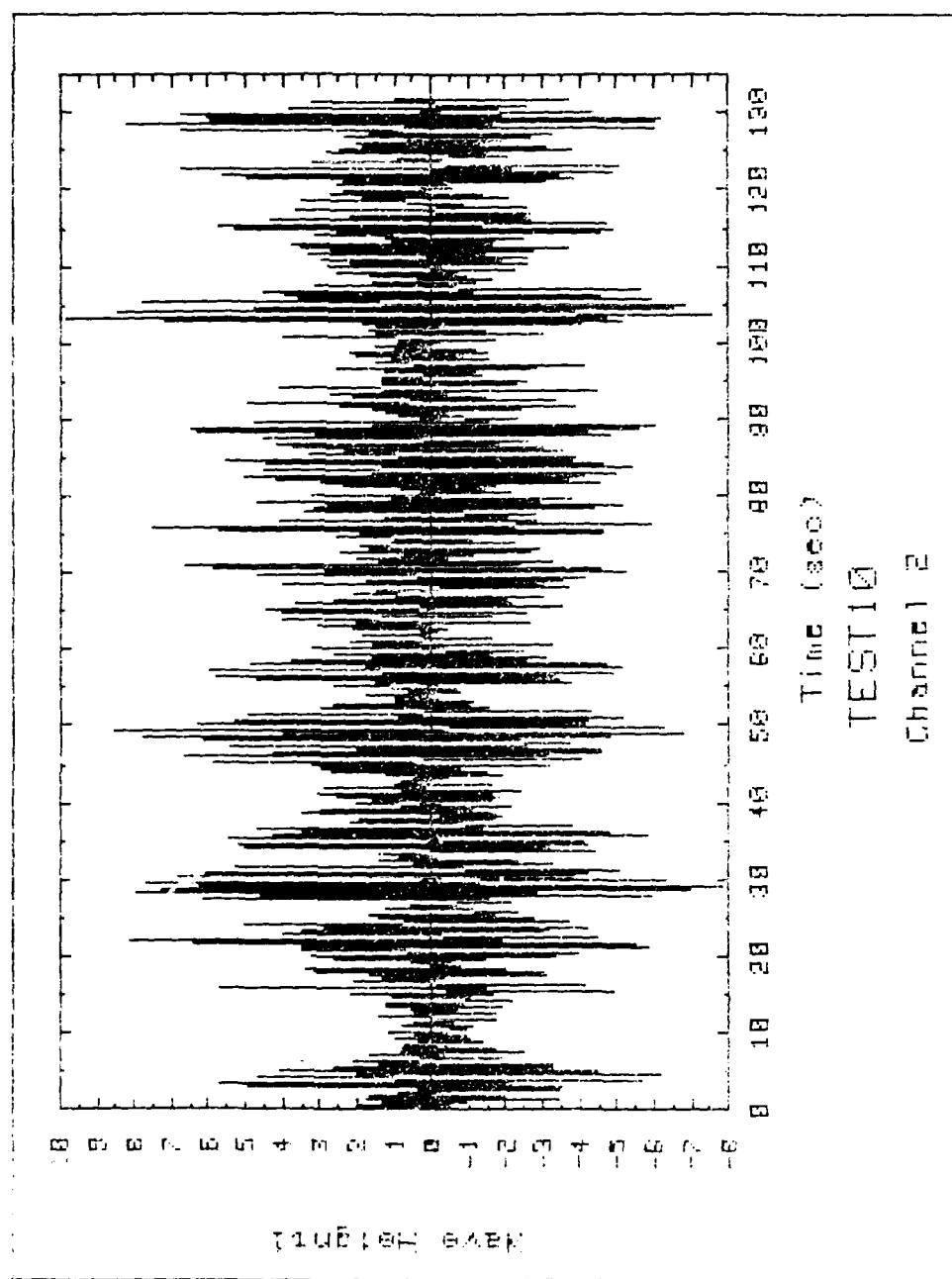
TEST 101

Chromat 1



Cumulative Distribution Function ( $t = \infty$ )

.92 .1 .51 2 5 13 2830 56 7662 9695 99 99.9



NAME	TYPE	NUMBER	WAVE	PERIOD
WAVE 1	SWELL	1	1.5	10.0
WAVE 2	SWELL	2	1.5	10.0
WAVE 3	SWELL	3	1.5	10.0
WAVE 4	SWELL	4	1.5	10.0
WAVE 5	SWELL	5	1.5	10.0
WAVE 6	SWELL	6	1.5	10.0
WAVE 7	SWELL	7	1.5	10.0
WAVE 8	SWELL	8	1.5	10.0
WAVE 9	SWELL	9	1.5	10.0
WAVE 10	SWELL	10	1.5	10.0
WAVE 11	SWELL	11	1.5	10.0
WAVE 12	SWELL	12	1.5	10.0
WAVE 13	SWELL	13	1.5	10.0
WAVE 14	SWELL	14	1.5	10.0
WAVE 15	SWELL	15	1.5	10.0
WAVE 16	SWELL	16	1.5	10.0
WAVE 17	SWELL	17	1.5	10.0
WAVE 18	SWELL	18	1.5	10.0
WAVE 19	SWELL	19	1.5	10.0
WAVE 20	SWELL	20	1.5	10.0
WAVE 21	SWELL	21	1.5	10.0
WAVE 22	SWELL	22	1.5	10.0
WAVE 23	SWELL	23	1.5	10.0
WAVE 24	SWELL	24	1.5	10.0
WAVE 25	SWELL	25	1.5	10.0
WAVE 26	SWELL	26	1.5	10.0
WAVE 27	SWELL	27	1.5	10.0
WAVE 28	SWELL	28	1.5	10.0
WAVE 29	SWELL	29	1.5	10.0
WAVE 30	SWELL	30	1.5	10.0
WAVE 31	SWELL	31	1.5	10.0
WAVE 32	SWELL	32	1.5	10.0
WAVE 33	SWELL	33	1.5	10.0
WAVE 34	SWELL	34	1.5	10.0
WAVE 35	SWELL	35	1.5	10.0
WAVE 36	SWELL	36	1.5	10.0
WAVE 37	SWELL	37	1.5	10.0
WAVE 38	SWELL	38	1.5	10.0
WAVE 39	SWELL	39	1.5	10.0
WAVE 40	SWELL	40	1.5	10.0
WAVE 41	SWELL	41	1.5	10.0
WAVE 42	SWELL	42	1.5	10.0
WAVE 43	SWELL	43	1.5	10.0
WAVE 44	SWELL	44	1.5	10.0
WAVE 45	SWELL	45	1.5	10.0
WAVE 46	SWELL	46	1.5	10.0
WAVE 47	SWELL	47	1.5	10.0
WAVE 48	SWELL	48	1.5	10.0
WAVE 49	SWELL	49	1.5	10.0
WAVE 50	SWELL	50	1.5	10.0
WAVE 51	SWELL	51	1.5	10.0
WAVE 52	SWELL	52	1.5	10.0
WAVE 53	SWELL	53	1.5	10.0
WAVE 54	SWELL	54	1.5	10.0
WAVE 55	SWELL	55	1.5	10.0
WAVE 56	SWELL	56	1.5	10.0
WAVE 57	SWELL	57	1.5	10.0
WAVE 58	SWELL	58	1.5	10.0
WAVE 59	SWELL	59	1.5	10.0
WAVE 60	SWELL	60	1.5	10.0
WAVE 61	SWELL	61	1.5	10.0
WAVE 62	SWELL	62	1.5	10.0
WAVE 63	SWELL	63	1.5	10.0
WAVE 64	SWELL	64	1.5	10.0
WAVE 65	SWELL	65	1.5	10.0
WAVE 66	SWELL	66	1.5	10.0
WAVE 67	SWELL	67	1.5	10.0
WAVE 68	SWELL	68	1.5	10.0
WAVE 69	SWELL	69	1.5	10.0
WAVE 70	SWELL	70	1.5	10.0
WAVE 71	SWELL	71	1.5	10.0
WAVE 72	SWELL	72	1.5	10.0
WAVE 73	SWELL	73	1.5	10.0
WAVE 74	SWELL	74	1.5	10.0
WAVE 75	SWELL	75	1.5	10.0
WAVE 76	SWELL	76	1.5	10.0
WAVE 77	SWELL	77	1.5	10.0
WAVE 78	SWELL	78	1.5	10.0
WAVE 79	SWELL	79	1.5	10.0
WAVE 80	SWELL	80	1.5	10.0
WAVE 81	SWELL	81	1.5	10.0
WAVE 82	SWELL	82	1.5	10.0
WAVE 83	SWELL	83	1.5	10.0
WAVE 84	SWELL	84	1.5	10.0
WAVE 85	SWELL	85	1.5	10.0
WAVE 86	SWELL	86	1.5	10.0
WAVE 87	SWELL	87	1.5	10.0
WAVE 88	SWELL	88	1.5	10.0
WAVE 89	SWELL	89	1.5	10.0
WAVE 90	SWELL	90	1.5	10.0
WAVE 91	SWELL	91	1.5	10.0
WAVE 92	SWELL	92	1.5	10.0
WAVE 93	SWELL	93	1.5	10.0
WAVE 94	SWELL	94	1.5	10.0
WAVE 95	SWELL	95	1.5	10.0
WAVE 96	SWELL	96	1.5	10.0
WAVE 97	SWELL	97	1.5	10.0
WAVE 98	SWELL	98	1.5	10.0
WAVE 99	SWELL	99	1.5	10.0
WAVE 100	SWELL	100	1.5	10.0

Ch 2: Tot Energy: 7.99; Hsg: 11.31; Peak Per.: 1.815

TEST 10

FEQ

4  
3  
2  
1  
0

Energy (cmag - sec)

•.83

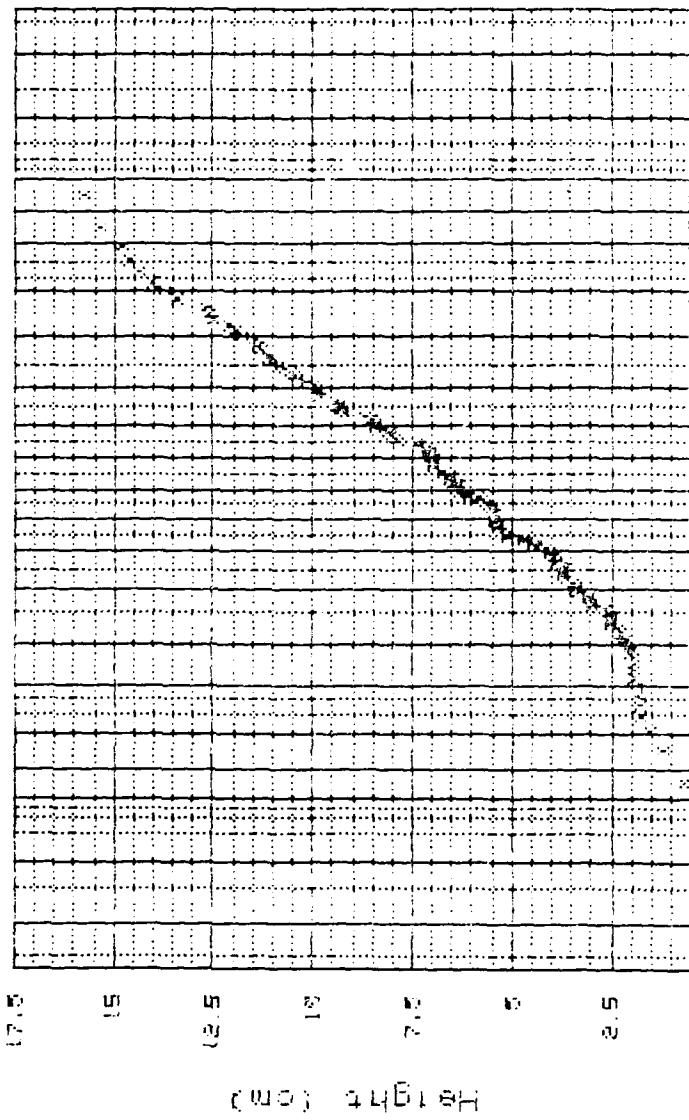
•.85

•.84

TEST 10  
Channel 2

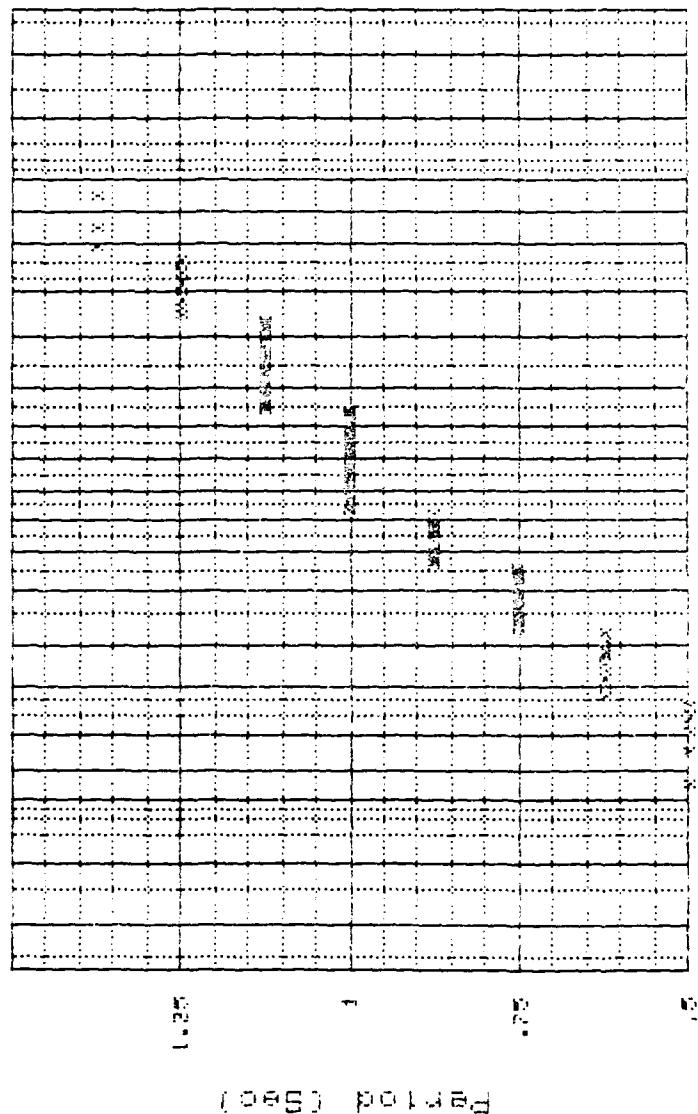
Cumulative Distribution Function ( $F(x)$ )

.02 .1 .2 .5 .10 .20 .30 .50 .70 .60 .90 .95 .99 .995 .999 .9995



TEST 10  
Channel 2

Cumulative Distribution Function ( $\phi = 23$ )



END

DATE  
FILMED

7-86

DTIC